In this section, terrestrial wildlife refers only to mammals and birds; no reptiles or amphibians are included in the TRIM.FaTE library at this time. The phrase "terrestrial wildlife" also includes the semi-aquatic species noted in the introduction to this chapter (*e.g.*, mink, loon). The text box on the next page and continued on the following pages provides a summary of the transfer-factor algorithms developed in this section and defines the parameters used in those algorithms.

7.4.1 GENERALIZED MODEL FOR TERRESTRIAL MAMMALS AND BIRDS

A generalized model for terrestrial wildlife (*Twl*), including all of the possible routes of exposure and of elimination, is presented below. In addition, the equation below applies to semi-aquatic populations, such as loons and raccoons. If particular rate constants are determined to be insignificant relative to others for a particular implementation of TRIM.FaTE (*e.g.*, excretion via eggs compared to excretion in urine or feces), those may be set to zero. Similarly, if rate constants for excretion and chemical transformation are determined with respect to the mass of a contaminant that is taken up in the diet rather than the mass that is assimilated, the dietary assimilation efficiencies may be ignored.

$$\begin{aligned}\frac{dC_{Twl}}{dt} &= [(IN_W \times C_{SW} \times AE_W) + (IN_{Ss} \times C_{Ss} \times AE_S) + p_{Plant}(IN_D \times C_{Leaf} \times AE_{Plant}) + \\ &p_{Plant}(IN_D \times C_{LeafP} \times AE_S) + p_{Worm}(IN_D \times C_{Worm} \times AE_{Worm}) \\ &+ p_{Arth}(IN_D \times C_{Arth} \times AE_{Arth}) + p_{Twl-prey}(IN_D \times C_{Twl-prey} \times AE_{Twl}) \\ &+ p_{fish}(IN_D \times C_{fish} \times AE_{fish}) + p_{BI}(IN_D \times C_{BI} \times AE_{BI}) + (IN_{Air} \times C_{Air} \times AE_{Air})] \\ &- [C_{Twl} \times (E_{met} + E_{uf} + E_{lact} + E_{egg} + E_{ff})]\end{aligned} \qquad \text{(Eq. 7-64)}$$

where:

C_{Twl}	=	total, whole-body, internal concentration in the terrestrial wildlife population (g[chemical]/kg[body wet wt]);
IN_W	=	water ingestion rate (m^3[water]/kg[body wet wt]-day);
C_{SW}	=	concentration of chemical in surface water ingested by wildlife (g[chemical]/m^3[water]);
AE_W	=	assimilation efficiency of chemical from water (unitless);
IN_{Ss}	=	surface soil ingestion rate (kg[soil dry wtl]/kg[body wet wt]-day);
C_{Ss}	=	concentration of chemical in surface soil (g[chemical]/kg[soil wet wt]);
AE_S	=	assimilation efficiency of chemical from soil (unitless);
p_{Plant}	=	proportion of plant matter in diet (unitless);
IN_D	=	diet ingestion rate normalized to body weight (kg[diet wet wt]/kg[body wet wt]-day);
C_{Leaf}	=	concentration of chemical in leaf component of diet (g[chemical]/kg[leaf wet wt]);

Summary of Transfer Factors for Wildlife in TRIM.FaTE

ADVECTIVE TRANSFERS

Surface water to semi-aquatic terrestrial wildlife (*i.e.*, bird or mammal): TF 7-21

$$T_{SW \rightarrow Twl} = Biomass_{Twl} \times \frac{IN_W \times AE_W}{V_{SW}}$$

Surface soil to terrestrial wildlife: TF 7-22

$$T_{Ss \rightarrow Twl} = Biomass_{Twl} \times \frac{IN_{Ss} \times AE_S}{V_{Ss} \times \rho_{Ss\_wet}}$$

Plant leaf to terrestrial wildlife: TF 7-23

$$T_{Leaf \rightarrow Twl} = \frac{\rho area_{Twl}}{\rho area_{Leaf}} \times p_{Plant} \times IN_D \times AE_{Plant}$$

Surface particles on plant leaf to terrestrial wildlife: TF 7-24

$$T_{LeafP \rightarrow Twl} = \frac{p_{LeafP} \times IN_D \times AE_S}{V_{LeafP} \times \rho_{LeafP}}$$

Earthworm to terrestrial vertebrate: TF 7-25

$$T_{Worm \rightarrow Twl} = \frac{\rho area_{Twl}}{\rho area_{Worm}} \times p_{Worm} \times IN_D \times AE_{Worm}$$

Soil arthropod to terrestrial vertebrate: TF 7-26

$$T_{Arth \rightarrow Twl} = \frac{\rho area_{Twl}}{\rho area_{Arth}} \times p_{Arth} \times IN_D \times AE_{Arth}$$

Terrestrial vertebrate to terrestrial vertebrate: TF 7-27

$$T_{Twl-prey-i \rightarrow Twl} = \frac{\rho area_{Twl}}{\rho area_{Tprey-i}} \times p_{Tprey-i} \times IN_D \times AE_{Twl}$$

Summary of Transfer Factors for Wildlife in TRIM.FaTE (cont.)

ADVECTIVE TRANSFERS (cont.)

Fish to terrestrial wildlife (*i.e.*, bird or mammal): TF 7-28

$$T_{fish-i \rightarrow Twl} = \frac{Biomass_{Twl}}{A_{SW} \times \rho area_{fish-i}} \times p_{fish-i} \times IN_D \times AE_{fish}$$

Benthic invertebrate or flying insect to terrestrial wildlife: TF 7-29

$$T_{BI \rightarrow Twl} = \frac{Biomass_{Twl}}{A_{Sed} \times \rho area_{BI}} \times p_{BI} \times IN_D \times AE_{BI}$$

Air to terrestrial wildlife: TF 7-30

$$T_{Air \rightarrow Twl} = Biomass_{Twl} \times \frac{IN_{Air} \times AE_{Air}}{V_{Air}}$$

Terrestrial wildlife to surface soil: TF 7-31

$$T_{Twl \rightarrow Ss} = f_{fuSs} \times k_{ET}$$

Terrestrial wildlife to water: TF 7-32

$$T_{Twl \rightarrow SW} = f_{fuSW} \times k_{ET}$$

LIST OF SYMBOLS USED IN WILDLIFE TRANSFER FACTOR ALGORITHMS:

$Biomass_{Twl}$	=	biomass of terrestrial wildlife species in a compartment (kg[wildlife wet wt]), which
	=	$\rho area_{Twl}$ (kg[wildlife wet wt]/m^2]) × A_S (m^2[soil]).
IN_W	=	water ingestion rate normalized to body weight (m^3[water]/kg[body wet wt]-day).
V_{SW}	=	volume of surface water compartment (m^3).
AE_W	=	assimilation efficiency of chemical from water (unitless).
IN_{Ss}	=	surface soil ingestion rate (kg[soil dry wt]/kg[body wet wt]-day).
V_{Ss}	=	volume of surface soil compartment (m^3).
ρ_{Ss}	=	density of soil particles (kg[soil dry wt]/m^3[soil]).
AE_S	=	assimilation efficiency of chemical from soil (unitless).
$\rho area_{Twl}$	=	terrestrial wildlife biomass density per unit area (kg[wildlife wet wt]/m^2[surface parcel]), which
	=	N_{area} (number[individuals]/m^2[soil]) × BW (kg[body wet wt]).
p_{Plant}	=	proportion of plant matter in diet (unitless).
IN_D	=	diet ingestion rate (kg[diet wet wt]/kg[body wet wt]-day).
AE_{Plant}	=	assimilation efficiency of chemical from plant in diet (unitless).
$\rho area_{Leaf}$	=	areal biomass density of foliage (kg[leaves wet wt]/m^2[surface soil]).
$\rho area_{LeafP}$	=	areal biomass density of particles on leaf surface (kg[leaf particles]/m^2[surface parcel]).
p_{Worm}	=	proportion of earthworm in diet (unitless).
AE_{Worm}	=	assimilation efficiency of chemical from earthworm in diet (unitless).

Summary of Transfer Factors for Wildlife in TRIM.FaTE (cont.)

LIST OF SYMBOLS USED IN WILDLIFE TRANSFER FACTOR ALGORITHMS (cont.)

$\rho area_{Worm}$	=	areal biomass density of earthworms (kg[worms wet wt]/m^2[soil]).
p_{Arth}	=	proportion of soil arthropods in diet (unitless).
AE_{Arth}	=	assimilation efficiency of chemical from soil arthropods in diet (unitless).
$p_{Twl\text{-}prey\text{-}i}$	=	proportion of terrestrial wildlife prey species *i* in diet (unitless).
$AE_{Twl\text{-}prey}$	=	assimilation efficiency of chemical from wildlife prey in diet (unitless).
$\rho area_{Twl\text{-}prey\text{-}i}$	=	areal biomass density of terrestrial wildlife prey species *i* in diet (kg[prey wet wt]/m^2[surface parcel]).
$p_{fish\text{-}i}$	=	proportion of fish species *i* in diet (unitless).
AE_{fish}	=	assimilation efficiency of chemical from fish in diet (unitless).
$\rho area_{fish\text{-}i}$	=	areal biomass density of fish species *i* (kg[fish wet wt]/m^2[surface water], use correct size range for diet).
A_{SW}	=	area of surface water compartment (m^2).
p_{BI}	=	proportion of benthic invertebrates (or emergent flying insects) in diet (unitless).
AE_{BI}	=	assimilation efficiency of chemical from benthic invertebrates (or flying insects) in diet (unitless).
$\rho area_{BI}$	=	areal biomass density of benthic invertebrates (kg[invertebrates wet wt]/m^2[sediment]).
A_{Sed}	=	area of sediment compartment (m^2).
IN_{Air}	=	inhalation rate normalized to body weight (m^3[air]/kg[body wet wt]-day).
V_{Air}	=	volume of air compartment (m^3[air]).
AE_{Air}	=	assimilation efficiency of chemical from air (unitless).
k_{ET}	=	chemical elimination rate constant (through feathers or fur and urine and feces) (/day).
f_{fuSW}	=	fraction of elimination directed to surface water (unitless).
f_{fuSs}	=	fraction of elimination directed to surface soil (unitless).

AE_{Plant}	=	assimilation (absorption) efficiency of chemical from plant in diet (unitless);
C_{LeafP}	=	concentration of chemical in particles on leaves (g[chemical]/kg[particles on leaf dry wt]);
p_{Worm}	=	proportion of earthworm in diet (unitless);
C_{Worm}	=	concentration of chemical in earthworms (g[chemical]/kg[worm wet wt]);
AE_{Worm}	=	assimilation (absorption) efficiency of chemical from earthworm in diet (unitless);
p_{Arth}	=	proportion of insect in diet (unitless);
C_{Arth}	=	concentration of chemical in soil arthropod component of the diet (g[chemical]/kg[arthropod wet wt]);
AE_{Arth}	=	assimilation (absorption) efficiency of chemical from soil arthropods in diet (unitless);
$p_{Twl\text{-}prey}$	=	proportion of other wildlife in diet (unitless);
$C_{Twl\text{-}prey}$	=	concentration of chemical in the prey of the terrestrial wildlife (g[chemical]/ kg[prey wet wt]);
$AE_{Twl\text{-}prey}$	=	assimilation (absoprtion) efficiency of chemical from other wildlife in diet (unitless);
p_{fish}	=	proportion of fish in diet (by fish compartment type) (unitless);

C_{fish} = concentration of chemical in fish (by fish type) (g[chemical]/kg[fish wet wt]; use correct size range);
AE_{fish} = assimilation (absorption) efficiency of chemical from fish in diet (unitless);
p_{BI} = proportion of benthic invertebrates (or emergent flying insects) in diet (unitless);
C_{BI} = concentration of chemical in benthic invertebrates (or flying insects) (g[chemical]/kg[invertebrates wet wt]);
AE_{BI} = assimilation (absorption) efficiency of chemical from benthic invertebrates or emergent flying insects in diet (unitless);
IN_{Air} = normalized inhalation rate (m^3[air]/kg[body wet wt]-day);
C_{Air} = concentration of chemical in the air, including vapor phase and particles (g[chemcial]/m^3[air]);
AE_{Air} = assimilation (absorption) efficiency of chemical from air (unitless);
E_{met} = rate of metabolic transformation to another chemical(s) that is tracked in a given scenario or "degradation" to another chemical(s) that is not tracked in a given scenario (/day);
E_{uf} = rate of chemical elimination through excretory processes (urine and feces) (/day);
E_{lact} = rate of chemical elimination through lactation (milk production, mammals only) (/day);
E_{egg} = rate of chemical elimination through egg production, birds only (/day); and
E_{ff} = rate of chemical elimination to fur (hair) or feathers (/day).

Because the source of drinking water is not usually known and may include puddles, the uptake of the chemical from water has been ignored in initial TRIM.FaTE applications for all species except the semi-aquatic, which are associated with a single water body.

Thus, for a population:

$$\frac{dN_{Twl}}{dt} = \rho area_{Twl} \times A_S \times [\frac{IN_W \times N_{SW} \times AE_W}{V_{SW}} + \frac{IN_{Ss} \times N_{Ss} \times AE_S}{V_{Ss} \times \rho_{Ss}} + \frac{p_{Plant} \times IN_D \times N_{Leaf} \times AE_{Plant}}{A_{Ss} \times \rho area_{Leaf}}$$
$$\frac{p_{Plant} \times IN_D \times N_{LeafP} \times AE_S}{V_{LeafP} \times \rho_P} + \frac{p_{Worm} \times IN_D \times N_{Worm} \times AE_{Worm}}{A_S \times \rho area_{Worm}} + \frac{p_{Arth} \times IN_D \times N_{Arth} \times AE_{Arth}}{A_S \times \rho area_{Arth}}$$
$$+ \frac{p_{Twl-prey} \times IN_D \times N_{Twl-prey} \times AE_{Twl}}{A_S \times \rho area_{Twl-prey}} + \frac{p_{fish} \times IN_D \times N_{fish} \times AE_{fish}}{A_{SW} \times \rho area_{fish}} + \frac{p_{BI} \times IN_D \times N_{BI} \times AE_{BI}}{A_{Sed} \times \rho area_{BI}}$$
$$+ \frac{IN_{Air} \times N_{Air} \times AE_{Air}}{V_{Air}}] - [N_{Twl} \times (E_{met} + E_{uf} + E_{lact} + E_{egg} + E_{ff})] \quad \text{(Eq. 7-65)}$$

where:

N_{Twl} = mass of chemical in terrestrial wildlife species (g[chemical]);
$\rho area_{Twl}$ = wildlife biomass density per unit area (kg[biomass wet wt]/m^2[surface volume element]);

A_S	=	area of associated soil (m^2);
N_{SW}	=	mass of chemical in surface water source (g[chemical]);
V_{SW}	=	volume of surface water (m^3);
N_{Ss}	=	mass of chemical in surface soil (g[chemical]);
V_{Ss}	=	volume of surface soil (m^3);
ρ_{Ss_wet}	=	bulk density of soil (kg[soil wet wt]/m^3[soil]);
N_{Leaf}	=	mass of chemical in plant leaf (g[chemical]);
$\rho area_{Leaf}$	=	areal biomass density of foliage (kg[leaf wet wt]/m^2[surface soil]);
N_{LeafP}	=	mass of chemical in particles on leaf (g[chemical]);
V_{LeafP}	=	volume of particles on leaf (m^3[particles]);
ρ_P	=	density of particles on surface of leaf (kg[particles]/m^3[particles]);
N_{Worm}	=	mass of chemical in earthworm (g[chemical]);
$\rho area_{Worm}$	=	areal biomass density of earthworms (kg[worm wet wt]/m^2[soil]);
N_{Arth}	=	mass of chemical in soil arthropods (g[chemical]);
$\rho area_{Arth}$	=	areal biomass density of soil arthropods (kg[arthropod wet wt]/m^2[soil]);
$N_{Twl\text{-}prey}$	=	mass of chemical in the wildlife prey species (g[chemical]);
$\rho area_{Twl\text{-}prey}$	=	areal biomass density of the wildlife prey species (kg[body wet wt]/m^2);
N_{fish}	=	mass of chemical in the fish species (g[chemical]);
A_{SW}	=	area of surface water (m^2);
$\rho area_{fish}$	=	areal biomass density of the fish species (kg[fish wet wt]/m^2[surface water]);
N_{BI}	=	mass of chemical in benthic invertebrates (emergent flying insects) (g[chemical]);
A_{Sed}	=	area of sediment (m_2);
$\rho area_{BI}$	=	areal biomass density of benthic invertebrates (kg[invertebrates wet wt]/m^2[sediment]);
N_{Air}	=	total mass of chemical in air (g[chemical]); and
V_{Air}	=	volume of air (m^3).

7.4.2 TRANSFER-FACTOR ALGORITHMS

In TRIM.FaTE, each route of exposure and elimination indicated in the previous section is handled as a separate transfer factor, as described in subsections 7.4.2.1 through 7.4.2.12. In the following subsections, the subscript *Twl* refers to terrestrial wildlife, including the semi-aquatic wildlife species, because they breathe air.

7.4.2.1 Surface Water to Terrestrial Vertebrate Wildlife

The general transfer factor for ingesting a chemical while drinking surface water for a specific semi-aquatic wildlife species, either a bird or a mammal, is given by:

$$T_{SW \rightarrow Twl} = Biomass_{Twl} \times \frac{IN_W \times AE_W}{V_{SW}} \qquad \text{(TF 7-21)}$$

where:

$T_{SW \rightarrow Twl}$	=	transfer factor for transfer of chemical from surface water to bird or mammal (/day);
$Biomass_{Twl}$	=	total biomass of wildlife compartment (kg);
IN_W	=	water ingestion rate normalized to body weight (m^3[air]/kg[body wet wt]-day);
AE_W	=	assimilation efficiency of chemical from water (unitless);
V_{SW}	=	volume of surface water compartment from which the animal is drinking (m^3[water]);

and:

$$Biomass_{Twl} = \rho area_{Twl} \times A \quad \text{(Eq. 7-66)}$$

or:

$$Biomass_{Twl} = PN_{Twl} \times BW_{Twl} \quad \text{(Eq. 7-67)}$$

where:

$\rho area_{Twl}$	=	terrestrial wildlife wet biomass density per unit area (kg[biomass wet wt]/m^2[surface parcel]);
A	=	area of associated surface water compartment (*e.g.*, for loons and ducks) or area of associated soil compartment that borders surface water compartment (m^2);
PN_{Twl}	=	population size, or number of individuals in compartment (unitless); and
BW_{Twl}	=	body weight of the bird or mammal (kg).

(Note: In the current TRIM.FaTE library, the property *PopulationSize* in the wildlife compartments is actually calculated as *NumberofIndividualsPerSquareMeter* × *A*.)

The water ingestion rates for birds and mammals can be estimated from allometric equations that relate water ingestion rates to body weight, as described in Section 3.2 of EPA's (1993) *Wildlife Exposure Factors Handbook*. The allometric equations for water ingestion by mammals and birds are from Calder and Braun (1983):

$$WI_{mammals} = 0.099 \times BW^{0.90} \quad \text{(Eq. 7-68)}$$

$$WI_{birds} = 0.059 \times BW^{0.67} \quad \text{(Eq. 7-69)}$$

where:

WI	=	water ingestion rate (L/day); and
BW	=	body weight (kg[body wet wt]).

Therefore, the water ingestion rate normalized to body weight in m^3[water]/kg[body wet wt]-day is estimated by:[1]

$$IN_W\left(\frac{\text{m}^3}{\text{kg}-\text{day}}\right) = \frac{WI\left(\frac{\text{L}}{\text{day}}\right)}{BW(\text{kg})} \times 0.0001\left(\frac{\text{m}^3}{\text{L}}\right) \qquad \text{(Eq. 7-70)}$$

7.4.2.2 Surface Soil to Terrestrial Vertebrate Wildlife

The general transfer factor for incidental ingestion of chemical with surface soil by a specific bird or mammal is given by:

$$T_{Ss\rightarrow Twl} = Biomass_{Twl} \times \frac{IN_{Ss} \times AE_S}{V_{Ss} \times \rho_{Ss\_wet}} \qquad \text{(TF 7-22)}$$

where:

$T_{Ss\rightarrow Twl}$	=	transfer factor for transfer of chemical from surface soil to bird or mammal (/day);
IN_{Ss}	=	surface soil ingestion rate (kg[soil dry wt]/kg[body wet wt]-day);
AE_S	=	assimilation efficiency of chemical from soil (unitless);
V_{Ss}	=	volume of surface soil compartment (m^3); and
ρ_{Ss_wet}	=	bulk density of surface soil (kg[soil wet wt]/m^3[soil]).

To estimate the soil ingestion rate from data on the estimated percent soil in the consumed diet on a dry-weight basis (e.g., the data in Beyer et al. 1994), the following equations can be used, where:

IN_D	=	diet (no soil) ingestion rate (kg[diet wet wt]/kg[body wet wt]-day);
IN_{Ss}	=	ingestion rate of surface soil (kg[soil dry wt]/kg[body wet wt]-day);
IN_{D_dry}	=	dry diet (no soil) ingestion rate (kg[diet dry wt]/kg[body wet wt]-day); and
IN_{Total_dry}	=	total intake of dry food plus dry soil (kg[food + soil, dry wt]/kg[body wet wt]-day]).

Assuming the natural diet is 75 percent water:

$$IN_{D\_dry} = IN_D \times 0.25 \qquad \text{(Eq. 7-71)}$$

$$IN_{Total\_dry} = IN_{Ss} + IN_{D\_dry} \qquad \text{(Eq. 7-72)}$$

The data available in Beyer et al. (1994) and similar studies are in the form of:

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[1]The algorithm described in Equation 7-70 is associated with mammal and bird compartment types in the current TRIM.FaTE library.

f_{intake_soil} = fraction of total dry-weight intake that is soil (unitless).

Therefore:

$$IN_{Total\_dry} = IN_{D\_dry} / (1 - f_{intake\_soil}) \qquad \text{(Eq. 7-73)}$$

Substituting Equation 7-73 for IN_{Total_dry} in Equation 7-72, using $IN_D \times 0.25$ for IN_{D_dry}, and rearranging the equation yields:

$$IN_{Ss} = \frac{IN_D \times 0.25}{(1 - f_{intake\_soil})} - IN_D \times 0.25 \qquad \text{(Eq. 7-74)}$$

The transfer factor for surface soil to terrestrial vertebrates should only be used for birds and mammals that forage on the ground (Beyer et al. 1994). For example, black-capped chickadees are arboreal feeders and are rarely observed on the ground (Smith 1993), meaning that soil ingestion for this species would be negligible. Representative species that ingest soil as a consequence of their feeding habits include the mallard, mule deer, black-tailed deer, white-tailed deer, long-tailed vole, raccoon, white-footed mouse, woodcock, and bobwhite quail. Representative species that do not feed on the ground – and consequently ingest only negligible amounts of soil or none at all – include the tree swallow, red-tailed hawk, long-tailed weasel, mink, and black-capped chickadee.

7.4.2.3 Plant Leaf to Terrestrial Vertebrate Wildlife

The general transfer factor for bird or mammal ingestion of a chemical in plant leaves is given by:

$$T_{Leaf \rightarrow Twl} = \frac{\rho area_{Twl}}{\rho area_{Leaf}} \times p_{Plant} \times IN_D \times AE_{Plant} \qquad \text{(TF 7-23)}$$

where:

$T_{Leaf \rightarrow Twl}$ = transfer factor for transfer of chemical from plant leaf to bird or mammal(/day);
p_{Plant} = proportion of plant matter in diet (unitless);
IN_D = diet ingestion rate (kg[diet wet wt]/kg[body wet wt]-day);
AE_{Plant} = assimilation efficiency of chemical from plant in diet (unitless); and
$\rho area_{Leaf}$ = areal biomass density of foliage (kg[leaves wet wt]/m^2[surface soil]).

Note that:

$$\rho area_{Twl} = PN_{area} \times BW \qquad \text{(Eq. 7-74)}$$

and:

$$Biomass_{Twl} = PN_{area} \times A \times BW \qquad \text{(Eq. 7-75)}$$

where:

A	=	area of containing surface volume element (m^2); and
PN_{area}	=	population size or number of individuals per unit area ($/m^2$[soil]).

The transfer factor for plant leaf to terrestrial vertebrates is most relevant for herbivores, which feed entirely on plant matter. It also is relevant for omnivores, for which plant matter makes up a portion of their diet. This transfer factor is not relevant for carnivores or predators/scavengers. The proportion of plant matter in the diet (p_{Plant}) varies by species, by season, and by location of the population of interest. In initial applications of TRIM.FaTE, p_{Plant} has varied by species.

7.4.2.4 Particles on Leaf Surface to Terrestrial Vertebrate Wildlife

Ingestion of plant materials generally results in the ingestion of the particles that have settled on the plant surfaces. In some areas under some conditions, the coating of plants with particulate matter (*e.g.*, dust or soil particles) can be substantial. The general transfer factor for particles on leaf surfaces to a specific bird or mammal is given by:

$$T_{LeafP \rightarrow Twl} = \frac{p_{Plant} \times IN_D \times AE_S}{V_{LeafP} \times \rho_{LeafP}} \qquad \text{(TF 7-24)}$$

where:

$T_{LeafP \rightarrow Twl}$	=	transfer factor for transfer of chemical from particles-on-leaf compartment to bird or mammal compartment via ingestion (/day);
AE_S	=	assimilation efficiency of chemical from soil (unitless);
V_{LeafP}	=	volume of the particles-on-leaf compartment (m^3); and
ρ_{LeafP}	=	density of dust particles (kg[particles]/m^3[particles]).

7.4.2.5 Earthworm to Terrestrial Vertebrate Wildlife

The general transfer factor for earthworms to a specific bird or mammal is given by:

$$T_{Worm \rightarrow Twl} = \frac{\rho area_{Twl}}{\rho area_{Worm}} \times p_{Worm} \times IN_D \times AE_{Worm} \qquad \text{(TF 7-25)}$$

where:

$T_{Worm \rightarrow Twl}$	=	transfer factor for transfer of chemical from earthworm to bird or mammal (/day);
$\rho area_{Worm}$	=	areal biomass density of earthworms (kg[worm wet wt]/m^2 [soil]);
p_{Worm}	=	proportion of earthworm in diet (unitless); and

AE_{Worm}	=	assimilation efficiency of chemical from earthworm in diet (unitless).

This transfer factor is relevant in cases where the specific bird or mammal of interest is known to consume earthworms. Examples of species that ingest earthworms include the raccoon, short-tailed shrew, woodcock, and American robin.

7.4.2.6 Soil Arthropod to Terrestrial Vertebrate Wildlife

The general transfer factor for soil arthropods to a specific bird or mammal is given by:

$$T_{Arth \to Twl} = \frac{\rho area_{Twl}}{\rho area_{Arth}} \times p_{Arth} \times IN_D \times AE_{Arth} \qquad \text{(TF 7-26)}$$

where:

$T_{Arth \to Twl}$	=	transfer factor for transfer of chemical from soil arthropods to bird or mammal (/day);
$\rho area_{Arth}$	=	areal biomass density of soil arthropods (kg[arthropod wet wt]/m^2[soil]);
p_{Arth}	=	proportion of soil arthropods in diet (unitless); and
AE_{Arth}	=	assimilation efficiency of chemical from arthropods in diet (unitless).

This transfer factor is relevant in cases where the specific bird or mammal of interest is known to consume soil arthropods. Soil arthropods are invertebrates with segmented bodies and jointed limbs as adults, such as ants, beetles, spiders, grasshoppers, and centipedes and include their larval forms that dwell in the soil as well (*e.g.*, beetle grubs). Examples of wildlife species that consume soil arthropods include the shrew, woodcock, and white-footed mouse.

7.4.2.7 Terrestrial Vertebrate to Terrestrial Vertebrate Wildlife

The general transfer factor for bird or mammal ingestion of chemical in avian or mammalian prey is given by:

$$T_{prey-i \to Twl} = \frac{\rho area_{Twl}}{\rho area_{Tprey-i}} \times p_{Tprey-i} \times IN_D \times AE_{Twl} \qquad \text{(TF 7-27)}$$

where:

$T_{prey\text{-}i \to Twl}$	=	transfer factor for the transfer of chemical from the i^{th} terrestrial vertebrate prey species to the bird or mammal predator species (/day);
$\rho area_{Twl}$	=	areal biomass density of the consumer wildlife (*i.e.*, bird or mammal) species (kg[predator wet wt]/m^2[soil]);
$\rho area_{Tprey\text{-}i}$	=	areal biomass density of the prey wildlife (*i.e.*, bird or mammal) species (kg[prey wet wt]/m^2[soil]);
$p_{Tprey\text{-}i}$	=	proportion of i^{th} terrestrial vertebrate prey species in diet (unitless); and
AE_{Twl}	=	assimilation efficiency of chemical from birds or mammals in diet (unitless).

The transfer factor for terrestrial vertebrate to terrestrial vertebrate is only applicable to birds and mammals that are classified as terrestrial omnivores, carnivores, and predators/scavengers. Examples of species to which this transfer factor would apply include the red-tailed hawk, long-tailed weasel, and mink. Note that the assimilation efficiencies for a chemical in either avian or mammalian prey consumed by avian or mammalian predators are likely to be similar; hence, a single AE_{Twl} is specified.

7.4.2.8 Fish to Terrestrial Vertebrate Wildlife

The transfer factor for ingestion of a chemical in fish by a terrestrial vertebrate is relevant in cases where the bird or mammal of interest is known to consume fish species (*i.e.*, the bird or mammal is classified as a piscivore or an omnivore). Several types or species of fish can be represented in TRIM.FaTE, including benthic herbivores, omnivores, and carnivores, and water column herbivores, omnivores, and carnivores (see Chapter 6). Different species of piscivorous wildlife are more likely to catch certain types and sizes of fish than others (*e.g.*, the belted kingfisher is more likely to eat small water column herbivores and omnivores such as minnows and bluegill than larger carnivorous species of fish). The general transfer factor for fish to a specific bird or mammal is given by:

$$T_{fish-i \rightarrow Twl} = \frac{Biomass_{Twl}}{A_{SW} \times \rho area_{fish-i}} \times p_{fish-i} \times IN_D \times AE_{fish} \qquad \text{(TF 7-28)}$$

where:

$T_{fish\text{-}i \rightarrow Twl}$ = transfer factor for transfer of chemical from i^{th} type of fish to bird or mammal (/day);
$p_{fish\text{-}i}$ = proportion of i^{th} type of fish in diet (unitless);
AE_{fish} = assimilation efficiency of chemical from fish in diet (unitless);
A_{SW} = area of surface of surface water body compartment (m^2); and
$\rho area_{fish\text{-}i}$ = areal biomass density of the i^{th} type of fish (kg[fish wet wt]/m^2[surface water]).

7.4.2.9 Benthic Invertebrate to Terrestrial Vertebrate Wildlife

Benthic invertebrates include mayflies, dragonfly nymphs, crayfish, clams, and aquatic snails, which dwell primarily at the bottom of water bodies. Examples of wildlife species that consume benthic invertebrates are the mallard, raccoon, and belted kingfisher. The general transfer factor for ingestion of a chemical in benthic invertebrates by a specific bird or mammal is given by:

$$T_{BI \rightarrow Twl} = \frac{Biomass_{Twl}}{A_{Sed} \times \rho area_{BI}} \times p_{BI} \times IN_D \times AE_{BI} \qquad \text{(TF 7-29)}$$

where:

$T_{BI \rightarrow Twl}$	=	transfer factor for transfer of chemical from benthic invertebrates to bird or mammal (/day);
p_{BI}	=	proportion of benthic invertebrates in diet (unitless);
AE_{BI}	=	assimilation efficiency of chemical from benthic invertebrates in diet (unitless);
A_{Sed}	=	area of the sediment compartment (m^2); and
$\rho area_{BI}$	=	areal biomass density of benthic invertebrates (kg[invertebrates wet wt]/m^2 [sediment]).

The same transfer factor is used to represent flying insects consumed by birds (or bats) for species of insects with aquatic larval stages. For purposes of the model, the flying insects are assumed to have the same chemical concentrations in their tissues as they had when living underwater before metamorphosis into flying adults. Representative species that consume flying insects include the black-capped chickadee and tree swallow.

7.4.2.10 Air to Terrestrial Vertebrate Wildlife

The general transfer factor for inhalation of a chemical in air (vapor- and particulate-phase) to a specific bird or mammal is given by:

$$T_{Air \rightarrow Twl} = Biomass_{Twl} \times \frac{IN_{Air} \times AE_{Air}}{V_{Air}} \qquad \text{(TF 7-30)}$$

where:

$T_{Air \rightarrow Twl}$	=	transfer factor for transfer of chemical from air to bird or mammal (/day);
IN_{Air}	=	inhalation rate normalized to body weight (m^3[air]/kg[body wet wt]-day);
AE_{Air}	=	assimilation efficiency of chemical from air (unitless); and
V_{Air}	=	volume of air compartment (m^3).

The inhalation rates for birds and mammals are estimated from allometric equations that relate inhalation rates of captive animals to body weight, as described in Section 3.3 of EPA's (1993) *Wildlife Exposure Factors Handbook.* The allometric equation for inhalation rate (*IR*) by mammals is from Stahl (1967). For mammals:

$$IR = 0.5458 \times BW^{0.80} \qquad \text{(Eq. 7-76)}$$

where:

IR	=	inhalation rate (m^3[air]/day); and
BW	=	body weight (kg[body wet wt]).

The allometric equations for inhalation rate by birds are from Lasiewski and Calder (1971). For nonpasserine birds (*i.e.*, birds other than the perching songbirds):

$$IR = 0.4089 \times BW^{0.77} \qquad \text{(Eq. 7-77)}$$

However, adjustments are required to estimate the inhalation rates of free-living animals from these estimates, which are based on conditions used to measure standard metabolic rate of captive animals. For example, it may be appropriate to multiply the predicted *IR* from these allometric equations by a factor of 2 to 3 (USEPA 1993). The value used in initial TRIM.FaTE applications is 2.5.

Also, the inhalation rate for birds is for nonpasserine species only. Passerines tend to have a higher metabolic rate than nonpasserines for a given body weight. For example, the equations for basal metabolic rate (*BMR*) developed by Lasiewski and Dawson (1967) from almost 100 species of birds revealed the following differences:

For passerine birds: $$BMR = 128 \times BW^{0.724} \qquad \text{(Eq. 7-78)}$$

For nonpasserine birds: $$BMR = 77.6 \times BW^{0.723} \qquad \text{(Eq. 7-79)}$$

where:

BMR = basal metabolic rate (kcal/day);
BW = body weight (kg[body wet wt]/day).

In other words, the BMR of passerine birds is about 1.65 times higher than that of non-passerine birds. Similarly, the equations for free-living metabolic rate (FMR) developed by Nagy (1987) for passerines (N = 26) and nonpasserines (N = 24) indicated that the FMR of passerine birds is about 1.85 times higher than that of nonpasserine birds.

Thus, the equations for estimating the free-living inhalation rate (*FIR*) in m^3/day for birds and mammals may be derived as:

For all mammals: $$FIR = 0.5458 \times BW^{0.80} \times 2.5 \qquad \text{(Eq. 7-80)}$$

For nonpasserine birds: $$FIR = 0.4089 \times BW^{0.77} \times 2.5 \qquad \text{(Eq. 7-81)}$$

For passerine birds: $$FIR = 0.4089 \times BW^{0.77} \times 2.5 \times 1.75 \qquad \text{(Eq. 7-82)}$$

Thus, IN_{Air} (in m^3/kg[body wet wt]-day) in equation TF 7-30 is estimated by:

$$IN_{Air} = \frac{FIR}{BW} \qquad \text{(Eq. 7-83)}$$

where:

FIR = free-living inhalation rate (m^3/day).

7.4.2.11 Terrestrial Vertebrate Wildlife to Surface Soil

The general transfer factor for elimination of a chemical from a bird or mammal to surface soil is given by:

$$T_{Twl \rightarrow Ss} = f_{fuSs} \times k_{ET} \qquad \text{(TF 7-31)}$$

where:

$T_{Twl \rightarrow Ss}$ = transfer factor for transfer of chemical from bird or mammal to surface soil (/day);
f_{fuSs} = fraction eliminated to surface soil (instead of surface water) (unitless); and
k_{ET} = first-order rate constant for total elimination of chemical in urine and feces (E_{uf}) plus feathers or fur (E_{ff}) (/day), *i.e.*,
= $k_{uf} + k_{ff}$.

This single first-order elimination rate refers to the parent chemical (*i.e.*, undegraded, untransformed chemical). In addition to excretion in urine and feces, chemicals also can be excreted by birds into feathers and eggs and by mammals into hair, or fur, and milk. For the chemicals modeled in TRIM.FaTE to date, with the exception of methylmercury, this single elimination rate constant will be dominated by elimination in urine and feces. For the excretion of methylmercury from birds, feathers and eggs is similar in importance to urine and feces (see Table A-17 in Appendix A). Thus, in the case of birds and methylmercury, the rate constant for chemical elimination that reaches the soil, k_{ET}, is set equal to the rate constant for elimination in urine and feces plus the rate constant for elimination in feathers. Note that in the current TRIM.FaTE compartment design, excretion to eggs does not constitute movement of the chemical out of the bird population compartment, nor does milk represent movement out of mammal population compartment. A discussion of estimating elimination rate constants from metabolic studies is presented in the TRIM.FaTE user guidance.

7.4.2.12 Semi-aquatic Vertebrate Wildlife to Surface Water

The general transfer factor for elimination of a chemical from semi-aquatic wildlife to surface water is given by:

$$T_{Twl \rightarrow SW} = f_{fuSW} \times k_{ET} \qquad \text{(TF 7-32)}$$

where:

$T_{Twl \rightarrow SW}$ = transfer factor for transfer of chemical from bird or mammal to surface water (/day);
f_{fuSW} = fraction eliminated to surface water (unitless); which
= $1 - f_{uSs}$.

7.4.3 TRANSFORMATIONS AND DEGRADATION

Transformations of organic chemicals into metabolic by-products that are no longer tracked in TRIM.FaTE are modeled as transfers to the wildlife degradation/reaction sinks. See the TRIM.FaTE user guidance for discussion of identifying rate constants for metabolism separately from rate constants associated with chemical excretion and elimination back to the environment. Equation 2-64 (Chapter 2) is used to estimate the first-order metabolic degradation (in TRIM.FaTE, called "general degradation") rate constant, $k_{degradation}$, for an organic chemical. The transfer-factor algorithm for transfer of metabolic by-products to the wildlife degradation/reaction sink is simply equal to $k_{degradation}$.

It has been observed that first-order degradation rate constants generally scale as a function of body weight (BW) to a negative one quarter power (U.S. EPA 1992). Thus, $k_{degradation}$ for a species of interest may be derived from $k_{degradation}$ for a reference species using the following equation:

$$k_{degradation}(Twl) = k_{degradation}(ref) \times \frac{BW(Twl)^{-0.25}}{BW(ref)^{-0.25}} \quad \text{(Eq. 7-84)}$$

where:

$k_{degradation}(Twl)$	=	metabolic degradation rate constant for the terrestrial wildlife species in TRIM.FaTE (/day);
$k_{degradation}(ref)$	=	metabolic degradation rate constant for the reference laboratory animal (/day);
$BW(Twl)$	=	body weight for the terrestrial wildlife species in TRIM.FaTE (kg[body wet wt]); and
$BW(ref)$	=	body weight for the reference laboratory animal (kg[body wet wt]).

Metabolic transformations of chemicals among different compounds containing the same core chemical (*e.g.*, transformation among mercury species) are included in the TRIM.FaTE wildlife models. See Appendix A, Section A.3, for a discussion of mercury transformations in birds and mammals.

7.4.4 SEASONALITY

Seasonality of diet is partially reflected in the current TRIM.FaTE library algorithms. Herbivorous or omnivorous wildlife consume leaves of deciduous trees, grasses/herbs, and possibly agricultural crops only during the growing season, when such leaves are available. During the non-growing season, those types of vegetation are no longer available to wildlife for consumption. Applications to date have not included alternative dietary items (containing the modeled chemical) for herbivorous wildlife in winter. Wildlife species could migrate out of the area for the winter (*e.g.*, American robin) or switch to other foods during the winter (*e.g.*, deer begin stripping bark and move from deciduous areas to coniferous forest).

To reflect winter sleep, hibernation, or migration, the user may turn off wildlife algorithms during relevant seasons. Additionally, it may be appropriate to seasonally vary the diet of particular wildlife species.

7.4.5 USE OF TERRESTRIAL WILDLIFE COMPARTMENTS

The TRIM.FaTE model has been parameterized for many functional trophic groups of wildlife species. These are listed in Table 7-1. The parameters for which input is needed in a TRIM.FaTE simulation for these compartment types are presented in Appendix D.

Discussion on the selection of wildlife species for a TRIM.FaTE scenario and the association of different species with appropriate volume elements is provided in the TRIM.FaTE users guidance. The addition of wildlife populations to a TRIM.FaTE scenario will depend on the goals and objectives of the project as well as the ecosystem being modeled. In addition, the

Table 7-1
Terrestrial and Semi-aquatic Vertebrate Compartment Types in Current TRIM.FaTE Library

Functional Trophic Group	Compartment Type
Semi-aquatic piscivore[a]/predator	Belted kingfisher Common loon (water-based)[b] Mink
Semi-aquatic predator/scavenger	Bald eagle
Semi-aquatic aerial insectivore (*i.e.*, feeding on adults of emergent insects such as mayflies)	Tree swallow
Semi-aquatic omnivore	Mallard (water-based)[b] Raccoon
Terrestrial omnivore	American robin White-footed mouse
Terrestrial insectivore	Black-capped chickadee
Terrestrial predator/scavenger	Long-tailed weasel Red-tailed hawk
Terrestrial herbivore	Black-tailed deer Bobwhite quail Long-tailed vole Meadow vole Mule deer White-tailed deer
Terrestrial ground-invertebrate feeder	Short-tailed shrew Trowbridge shrew Woodcock

[a] Consumes fish.
[b] The containing volume element is associated with surface water, and the species' population density represents the number of individuals per unit surface water area.

distribution of chemical mass (and transfers) across wildlife biomass and trophic levels in the ecosystem needs consideration.

Exclusively terrestrial wildlife species may be associated with terrestrial surface volume elements depending on the plant community represented by the volume element (*e.g.*, deciduous forest, coniferous forest, herbs/grasses). The containing volume element for semi-aquatic wildlife species can either be a surface water volume element (*i.e.*, water-based species, such as loons, that spend most of their time on the water and feed entirely on aquatic organisms) or a surface soil volume element (*i.e.*, land-based species, such as mink that spend most of their time on land and consume both aquatic and terrestrial foods) (see Table 7-1).

Several semi-aquatic wildlife species have been included in the current TRIM.FaTE library. Each of these species must be linked to a specific surface water body from which they can obtain their aquatic prey or food (*e.g.*, fish, benthic invertebrates, macrophytes). This generally is accomplished by including the wildlife species' compartment in a land parcel that is adjacent to the surface water body and estimating the density and numbers of individuals present based on the area of the land parcel. Alternatively, it might be appropriate to create two different compartment types for these semi-aquatic wildlife (*e.g.*, raccoons consuming aquatic prey and raccoons consuming terrestrial prey), particularly for applications where aquatic species play a substantive role (*e.g.*, as focus in assessment, or significant source of pollutant to predators). The densities of the land-based semi-aquatic wildlife in the containing surface soil volume element should reflect only those individuals with foraging ranges that might realistically include the water body. For species that defend feeding territories, the number of individuals per unit length of shoreline would be the relevant density measure for those consuming aquatic prey. The density of that species per unit area of the containing surface soil volume element would equal the number of individuals that might forage along the interface between the surface water compartment and containing surface soil volume element divided by the area of the surface soil volume element. Otherwise, the simulation might reflect an unrealistic consumption of aquatic organisms by their land-based predators. For species that forage in flocks or herds far from nesting or breeding sites, such as tree swallows, the number of individuals per unit area of the terrestrial environment generally would be the relevant density measure.

Predators/scavengers with large home ranges (*e.g.*, bald eagle) can be modeled as consuming prey from a number of different surface parcels or volume elements. A TRIM.FaTE variable called *TheLink.Fraction-SpecificCompartmentDiet* in the transfer factor algorithm used for the ingestion link from the prey (and its associated surface parcel) to the predator would be used to partition the diet among different surface parcels.

7.4.6 ASSIMILATION EFFICIENCY AND ELIMINATION

The TRIM.FaTE user guidance discusses the types of data from published studies that may be appropriate to use for chemical assimilation (absorption) efficiencies from the diet (AE_D), from drinking water (AE_W), from air via inhalation (AE_{Air}), and for elimination rate constants (k_{ET}). Nonetheless, some explanation is warranted here to assist the user in understanding differences in the fish and wildlife values for AE and k_{ET} properties in the current TRIM.FaTE library. A simplified explanation of AE_D, AE_W, and k_{ET} for mammals and birds is presented in Section 7.4.6.1. A simplified explanation of AE_{Air} is provided in Section 7.4.6.2.

7.4.6.1 Efficiency of Chemical Assimilation from the Diet

An AE_D for dietary intake of a chemical (or an AE_W for intake of a chemical with drinking water) of 1.0 implies complete absorption from the diet/drinking water, while an AE_D of 0.2, for example, indicates that 80 percent of the chemical passed through the wildlife unabsorbed and hence, must have been eliminated in the feces. For the chemical that was absorbed (*e.g.*, 20 percent in the current example), there are several possible elimination routes listed below, the first three of which may be considered "excretory processes":

- excretion in urine (via the kidney);
- excretion in bile, which is eliminated in the feces;
- transfer to fur or feathers, to eggs, or to milk;
- exhalation via the lungs (considered a diffusive process of negligible magnitude for compounds of interest and not included in the current TRIM.FaTE library); and
- metabolic degradation to other chemicals.

Depending on the organism, available data by which to estimate one or more of these processes might be predominantly of one type or another. Many toxicokinetic studies using birds or mammals, where both feces and urine are fairly easy to collect and analyze, estimate "elimination" rates or rate constants based on those data. Those data account for (a) fecal elimination of the unabsorbed chemical, and excretion of the absorbed chemical (b) in urine and (c) in the bile. Many such studies also measure dose as the concentration of the chemical in the diet multiplied by the quantity of food eaten. With these types of measurements, one would not need to estimate an AE_D (or AE_W) for the chemical. Instead, all of the chemical ingested with food (and water) would represent the chemical gain rate for the wildlife compartment and chemical elimination in urine and feces would represent the loss rate. In this case, the AE_D (or AE_W) would be set equal to 1.0. Given that the mercury loss (elimination) rates for wildlife modeled in an initial mercury application were based on measurements of the quantity of chemical in urine and feces compared with the quantity in the diet and water, we set AE_D and AE_W to 1.0 for that test case.

Toxicokinetic studies of organic compounds often use radioactive labels to track the elimination of metabolites of organic compounds in urine and feces as well as elimination of the parent compound. In TRIM.FaTE, if the metabolites are not tracked further by the model, the mass of parent chemical that was degraded into metabolites should be transferred to a wildlife sink. Only the parent chemical that is excreted in urine and feces should be transferred back to the environment (either surface soil or surface water) via the “elimination” transfer factors. Thus, only those studies in which the investigator quantifies the radioactive metabolites separately from the radioactive parent chemical can be used to set a rate constant for transfer to the degradation sink separately from the rate constant for elimination to the environment.

Another type of data often reported in the literature are elimination rate constants based on measurements of body burdens of a chemical over time following a single administration. Suppose that a group of animals were administered an organic chemical one time by intravenous injection. Suppose further that the body burdens of the chemical in different subsets of those animals were measured at weekly intervals after that. From those data (*i.e.*, body burden at time 0, 7 days, 14 days, etc.), the estimated elimination rate constant would account for (a) excretion in urine, (b) excretion in bile (in feces), and (c) metabolic degradation to other chemicals. That is, these data (from an intravenous injection study) do not provide information on assimilation or absorption from the diet that is needed to estimate $AE_{D.}$ For additional discussion of these topics, see the TRIM.FaTE user guidance.

7.4.6.2 Efficiency of Chemical Assimilation from Air

In a very simple inhalation model, the efficiency of assimilation of a chemical from air can be calculated from the estimated inhalation dose (*i.e.*, the chemical concentration in air multiplied by the animal's inhalation rate, measured in volume of air per unit time) compared with the body burden of the chemical in the animal after a specified exposure duration. The estimated AE_{Air}, representing a net absorption, would account for transfers from the air in the lungs to the bloodstream and from the bloodstream to the air in the lungs.